

CLAIMS:

1. A method for fabricating tapered elements from a substrate having a size many times that of a single element, the method comprising:
 - providing a substrate having first and second major surfaces;
 - defining a first and second cutting directions that form an angle in relation to each other;
 - cutting the substrate a plurality of times along the first cutting direction to result in a first set of cuts, each cut being spaced from an adjacent cut by a first predetermined indexing distance; and
 - cutting the substrate a plurality of times along the second cutting direction resulting in second set of cuts, each cut being spaced from an adjacent cutting by a second predetermined indexing distance.
2. The method of claim 1, wherein the first and second predetermined indexing distances are substantially uniform such that the cuts in both cutting directions are equidistant.
3. The method of claim 1, further comprising:
 - defining a third cutting direction which transverses both the first and second cutting directions;
 - cutting the substrate a plurality of times along the third cutting direction to result in a third set of cuts, each cut being spaced from an adjacent cut by a third predetermined indexing distance.

20160102-026247004

4. The method of claim 3, wherein the third predetermined indexing distance is substantially uniform.

5. The method of claim 3, wherein the substrate has a dicing surface, and the steps of defining the first, second and third cutting directions further comprise:

providing at least three optically detectable marks on the dicing surface;

selecting a first pair of marks to define the first cutting direction;

selecting a second pair of marks to define the second cutting direction, wherein at least one mark in the second pair of marks is not included in the first pair of marks; and

selecting a third pair of marks to define the third cutting direction, wherein the third pair of marks is different from both the first and second pairs of marks by at least one mark.

6. The method of claim 5, wherein the dicing surface of the substrate has peripheral edges, and the first, the second, the third and the fourth marks are placed close to the peripheral edges such that the marks are separated from each other as far as possible while still accommodating proper cutting directions.

7. The method of claim 5, wherein the detectable marks include a first, second, third and fourth mark, the first pair of marks include the first and second marks, the second pair of marks include the third and fourth marks, and the third pair of marks include either the first and the third or the second and fourth fiducial marks.

2025 RELEASE UNDER E.O. 14176

8. The method of claim 6, wherein the first, the second, the third and the fourth fiducial marks are cross-hair type marks capable of optically indicating a precise reference point.

9. The method of claim 1, wherein the substrate comprises a piezoelectric material.

10. The method of claim 9, wherein the substrate is cut into an plurality of elements, each element being further adapted to be used as an microactuator.

11. The method of claim 1, further comprising:
forming isolation trenches on the substrate, the resultant isolation trenches being parallel to each other and aligned in a trench direction forming a first angle with the first cutting direction and a second angle with the second cutting direction, each trench being spaced from an adjacent trench by a trench distance.

12. The method of claim 11, wherein the substrate comprises a piezoelectric material, the substrate is cut into an plurality of elements, each element being adapted to be an in-plane piezoelectric bimorph, and the isolation trenches are adapted to divide each one of the in-plane piezoelectric bimorphs into two in-plane piezoelectric portions.

13. The method of claim 11, wherein the isolation trenches are formed using a method selected from a group consisted of photolithography, ion milling, reactive ion etching, and laser ablation.

20160705-A00024

14. The method of claim 11, wherein the first angle and the second angle are equal to each other.

15. The method of claim 11, wherein the trench distances between two adjacent parallel trenches are substantially uniform.

16. The method of claim 1, wherein the substrate has a dicing surface, and the steps of defining a first and second cutting directions further comprises:

- providing at least three optically detectable marks on the dicing surface;
- selecting a first pair of marks to define the first cutting direction;
- and
- selecting a second pair of marks to define the second cutting direction, wherein the second pair of marks include at least one mark which is not included in the first pair of marks.

17. An optically guided dicing method for making a plurality of 4-sided trapezoid elements from a substrate having a surface many times larger than that of a single element, each element having first and second opposing major sides, and a top and a bottom opposing each other, the top having a top width, the bottom having a bottom width which is greater than the top width, and each element further has a length measured from the bottom to the top, wherein the first and second angled major sides define a first identical feature angle of the 4-sided trapezoid elements, the bottom and the first or the second major side define a second identical feature angle of the 4-sided polygon-shaped elements, the method comprising:

- marking the surface of the substrate using a plurality of optically detectable marks, wherein the marks defining an n-sided ($n \geq 3$) guiding polygon having a size substantially greater

2025 RELEASE UNDER E.O. 14176

than that of a single 4-sided trapezoid element, the guiding polygon having a first and second angled opposing major sides defining an angle that is equal to the first identical feature angle of the elements, and a third side defining with one of the first and the second sides an angle equal to the second identical feature angle of the elements;

cutting the substrate a plurality of times along a first cutting direction parallel to the first angled opposing major side of the guiding polygon, each cut being spaced from an adjacent cut by the bottom width of the corresponding elements;

cutting the substrate a plurality of times along a second cutting direction parallel to the second angled opposing major side of the guiding polygon, each cut being spaced from an adjacent cut by the bottom width of the corresponding elements; and

cutting the substrate a plurality of times along a third cutting direction parallel to the third side of the guiding polygon, each cut being spaced from an adjacent cut by the length of the corresponding elements.

18. The method of claim 17, wherein the lengths of the plurality of elements are identical.

19. The method of claim 17, wherein the bottom widths of the plurality of elements are identical.

20. The method of claim 17, wherein the plurality of optically detectable marks include first, second, third and fourth marks defining of 4-sided guiding polygon.

21. An optically guided dicing method for making a plurality of trapezoid- shaped elements from a substrate having a surface many times larger than that of a single element, wherein each element has first and second angled opposing sides, a top, a bottom, and a major surface, the major surface bearing a vertical divider line crossing the top and the bottom to divide the major surface into first and second portions including the first and second angled opposing sides respectively, the first angled side and the divider line defining a first identical feature angle of the trapezoid elements, the second angled side and the divider line defining a second identical feature angle of the trapezoid elements, the bottom and one of the first and second sides defining a third identical feature angle of the trapezoid elements, the top having a top width, the bottom having a bottom width which is greater than the top width, and each element having a length measured from the bottom to the top; the method comprising:

- defining a vertical reference direction on the surface of the substrate;
- defining a first cutting direction which forms an angle equal to the first identical feature angle of the trapezoid elements in relation to the vertical reference direction;
- defining a second cutting direction which forms an angle equal to the second identical feature angle of the trapezoid elements in relation to the vertical reference direction;
- defining a third cutting direction which forms an angle equal to the third identical feature angle of the trapezoid elements in relation to one of the first and second cutting directions;

cutting the substrate a plurality of times along the first cutting direction, each cut being spaced from an adjacent cut by the bottom width of the corresponding elements;

cutting the substrate a plurality of times along the second cutting direction, each cut being spaced from an adjacent cut by the bottom width of the corresponding elements; and

cutting the substrate a plurality of times along the third cutting direction, each cut being spaced from an adjacent cut by the length of the corresponding elements.

22. The method of claim 21, wherein the first feature angle and the second feature angle are equal to each other, and the step of defining the second cutting direction comprises:

aligning cutting means along a direction that is symmetrical to the first cutting direction in relation to the vertical reference direction.

23. The method of claim 21, wherein the step of defining a vertical reference direction comprises:

forming a plurality of isolation trenches on the substrate, the resultant isolation trenches being parallel to each other and aligned in a trench direction which defines the vertical reference direction.

24. A tapered piezoelectric bimorph transducer fabricated from a piezoelectric substrate having a size many times that of the tapered piezoelectric bimorph transducer, wherein each tapered transducer has two angled opposing

sides, a top having a top width, and a bottom having a bottom width which is greater than the top width.

25. The device of claim 24, further comprising an isolation trench dividing the bimorph transducer into two in-plane piezoelectric portions.

26. The device of claim 25, wherein the two portions are symmetrical with respect to the isolation trench.

27. The device of claim 25, wherein the bimorph transducer is adapted to be an in-plane piezoelectric bimorph microactuator which is divided by the isolation trench into two in-plane piezoelectric portions.